Impact of cosmic web on halo formation

How does the cosmic web impact galaxy formation?

Corentin Cadiou
With S. Codis, Y. Dubois, C. Pichon

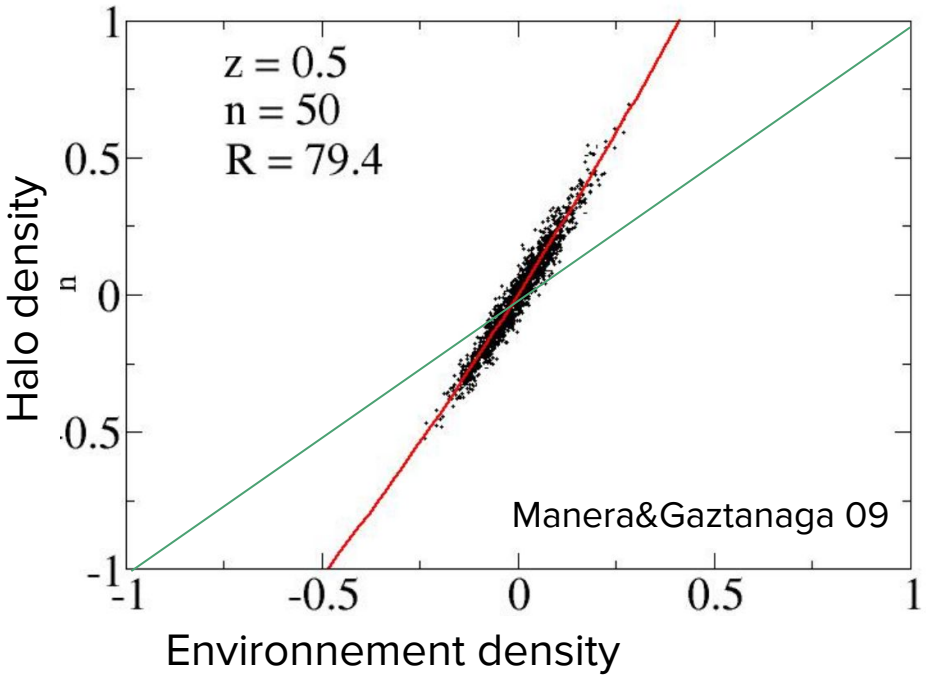
Ph.D. day — 2019

Introduction

The isotropic environnement

Press-Schechter 76: DM population can be predicted from initial conditions (**CMB**)

Kaiser 84: halo formation is not linear in *matter* density



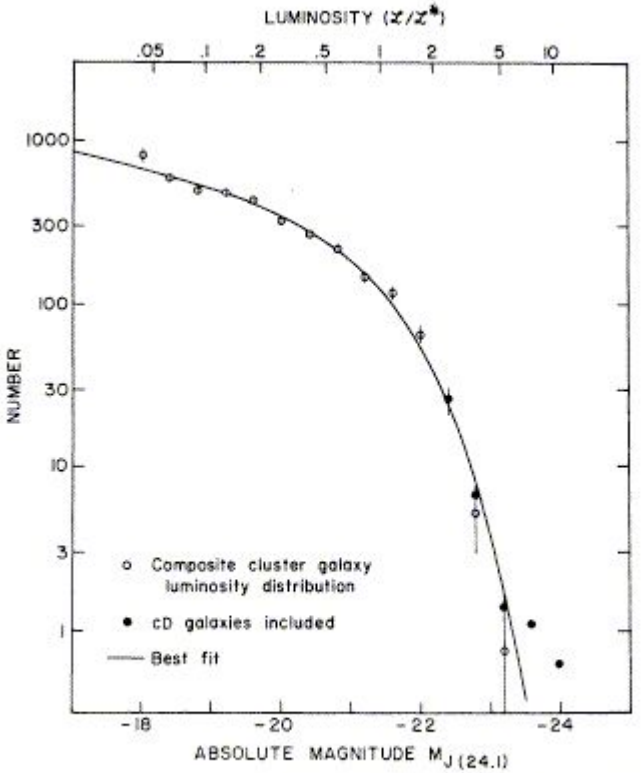


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Press&Schechter 76

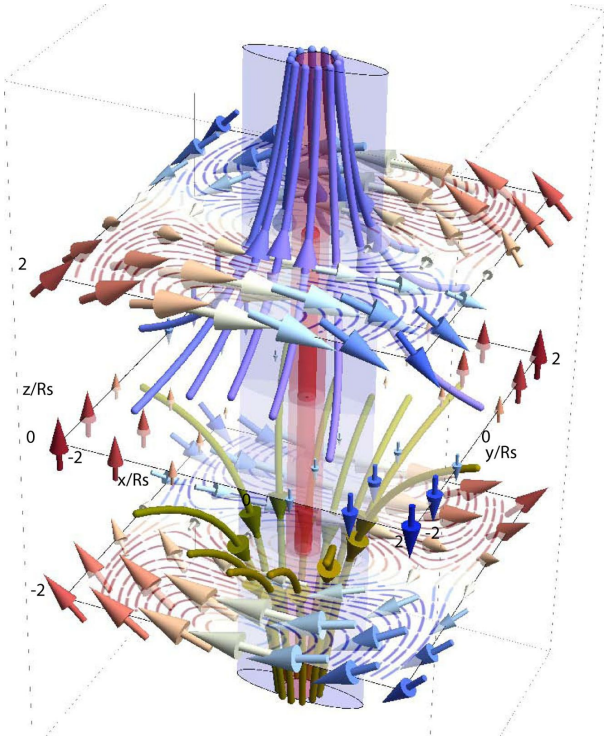
The **an**isotropic environnement

Galaxies do **not** grow anywhere ➜ woven in the cosmic web

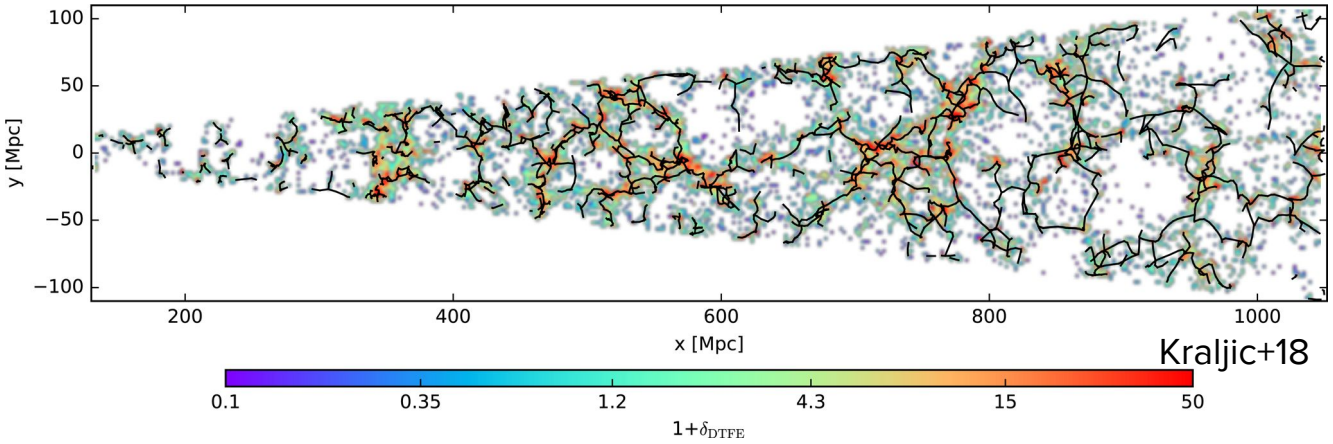
Galaxy properties: modulated with time **and** space!

- Spin aligned with cosmic filaments
- Galaxies younger/less massive in filaments than in voids

⇒ need to go beyond halo model



Codis+15

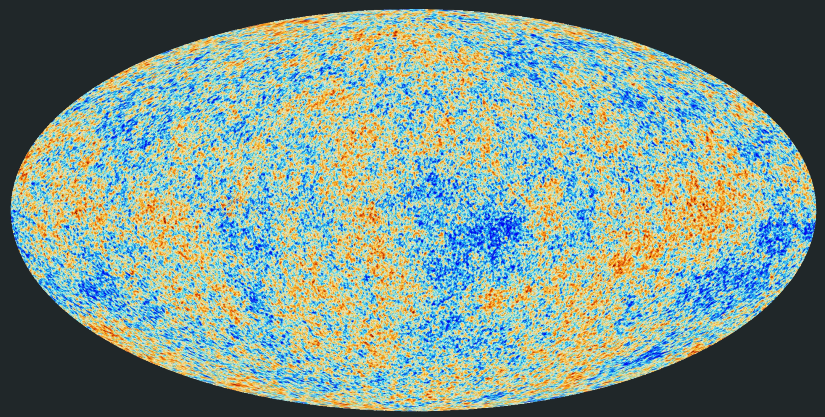


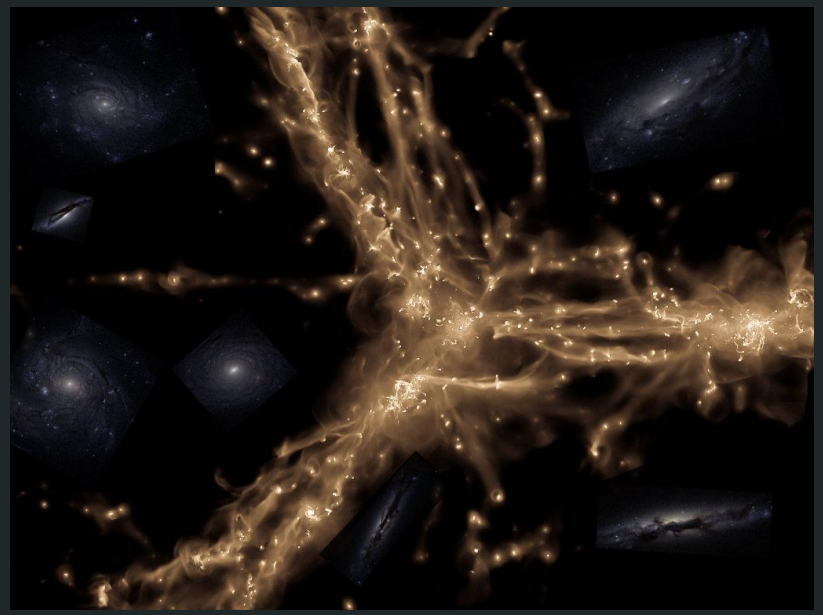
Kraljic+18

Can we understand the **spatial** modulations of galaxy properties?

Linking ICs and halo assembly

How is the accretion & merger history encoded in the initial conditions?





Probing galaxy formation from ICs

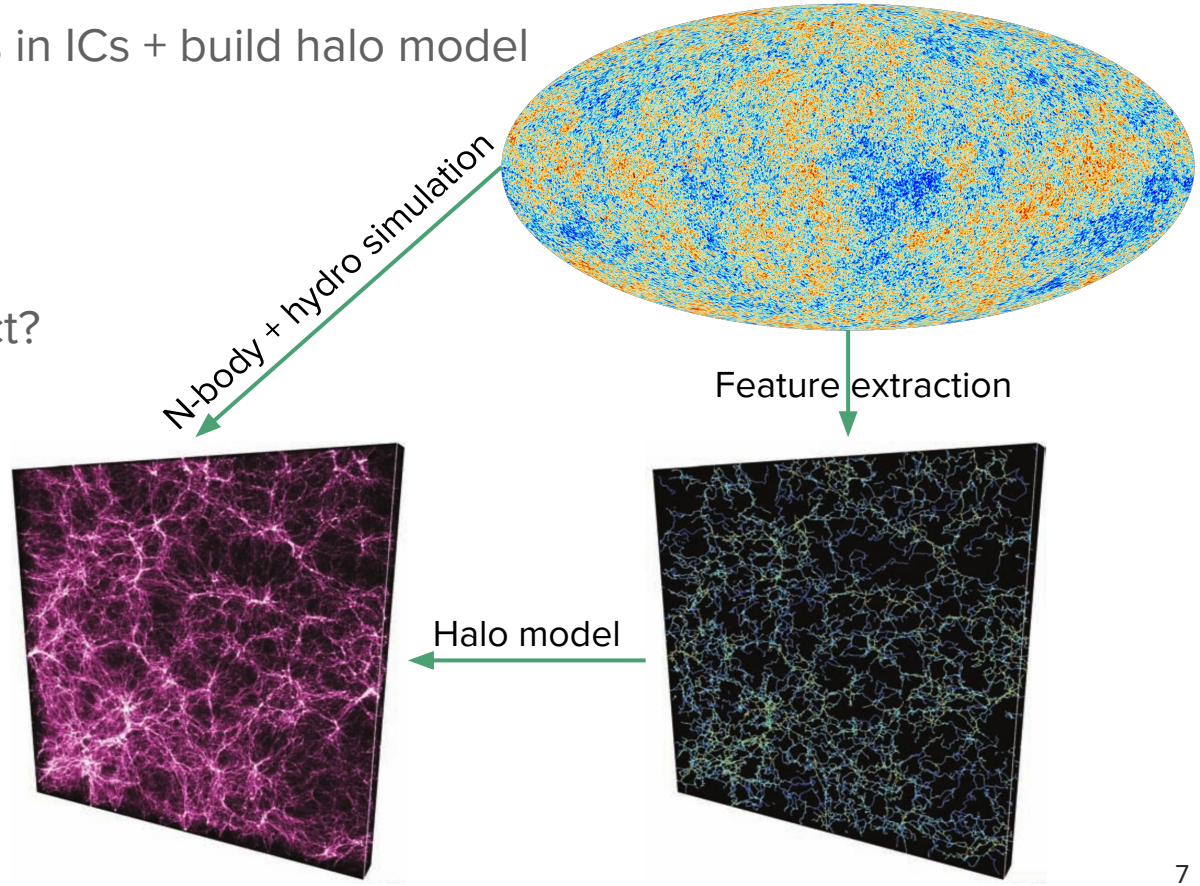
Two way to compute galaxy properties

1. Run costly n-body + hydro simulation (e.g. Horizon-AGN, Illustris, etc.)
   "The numerical way"

2. Extract relevant features in ICs + build halo model
   "The theoretical way"

Challenges:

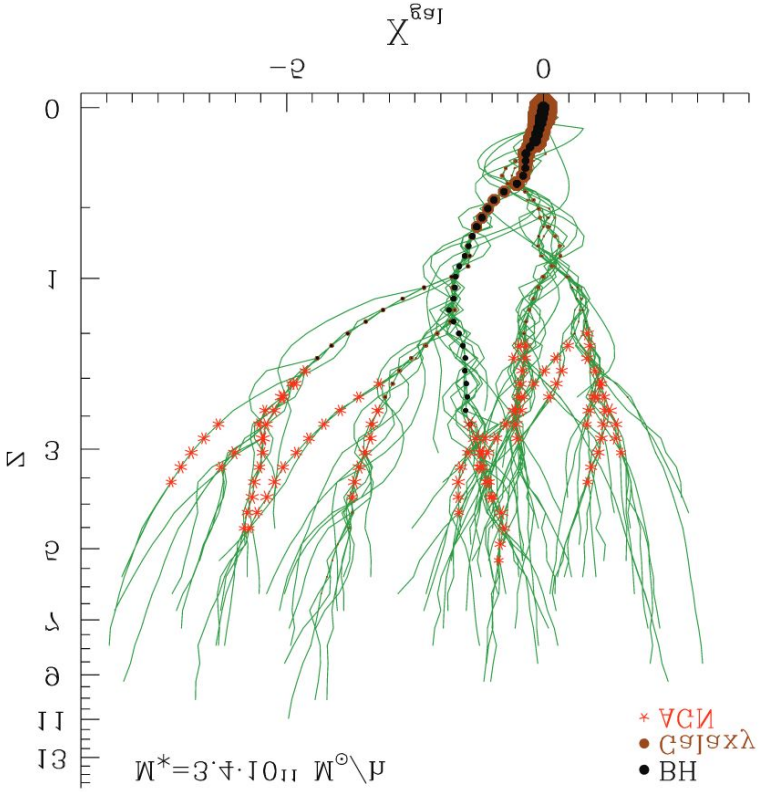
- What feature(s) to extract?
- What galaxy properties?
- Build good estimators to account for anisotropy
  (beyond 2-pt corr. functions)



The skeleton tree formalism

Can we build a merger-tree like structure from the initial conditions?

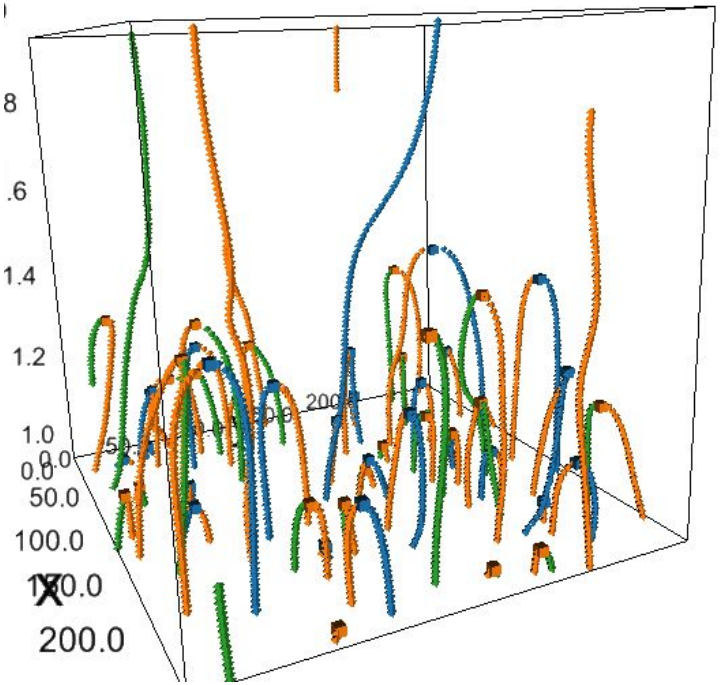
⇒ Yes! Study the topological structure of the ICs at different scales (Hanami 2001)



Marulli+2009

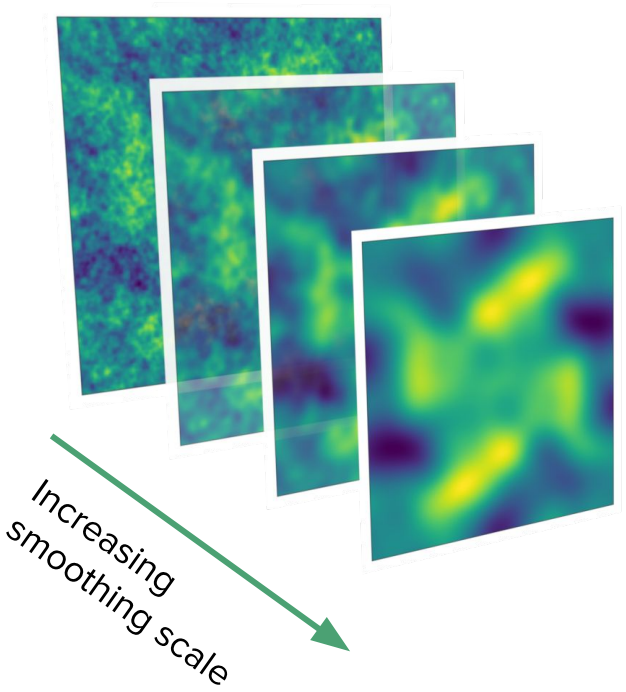
Time

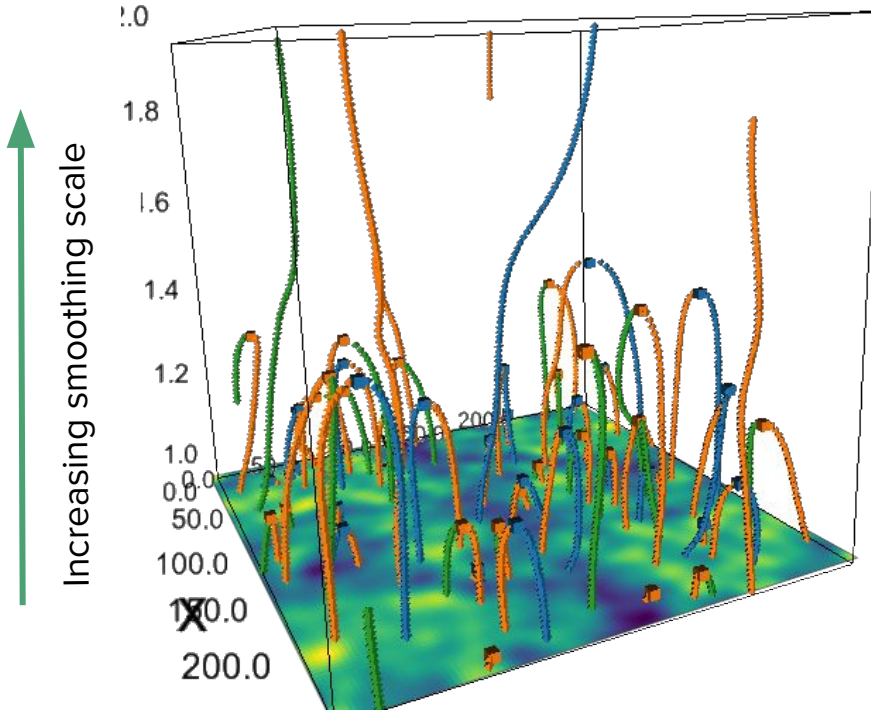
Smoothing scale

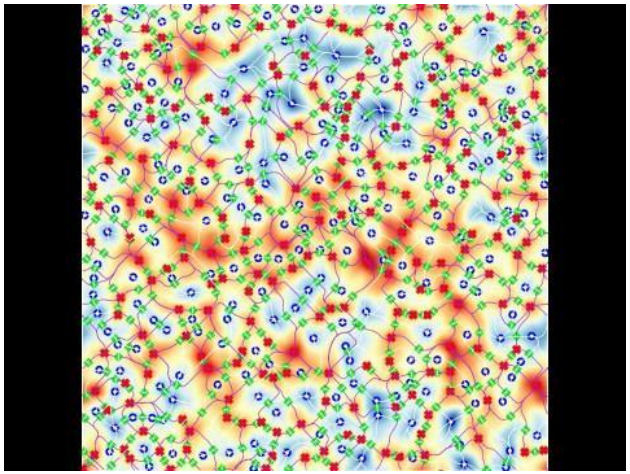


Cadiou+ in prep

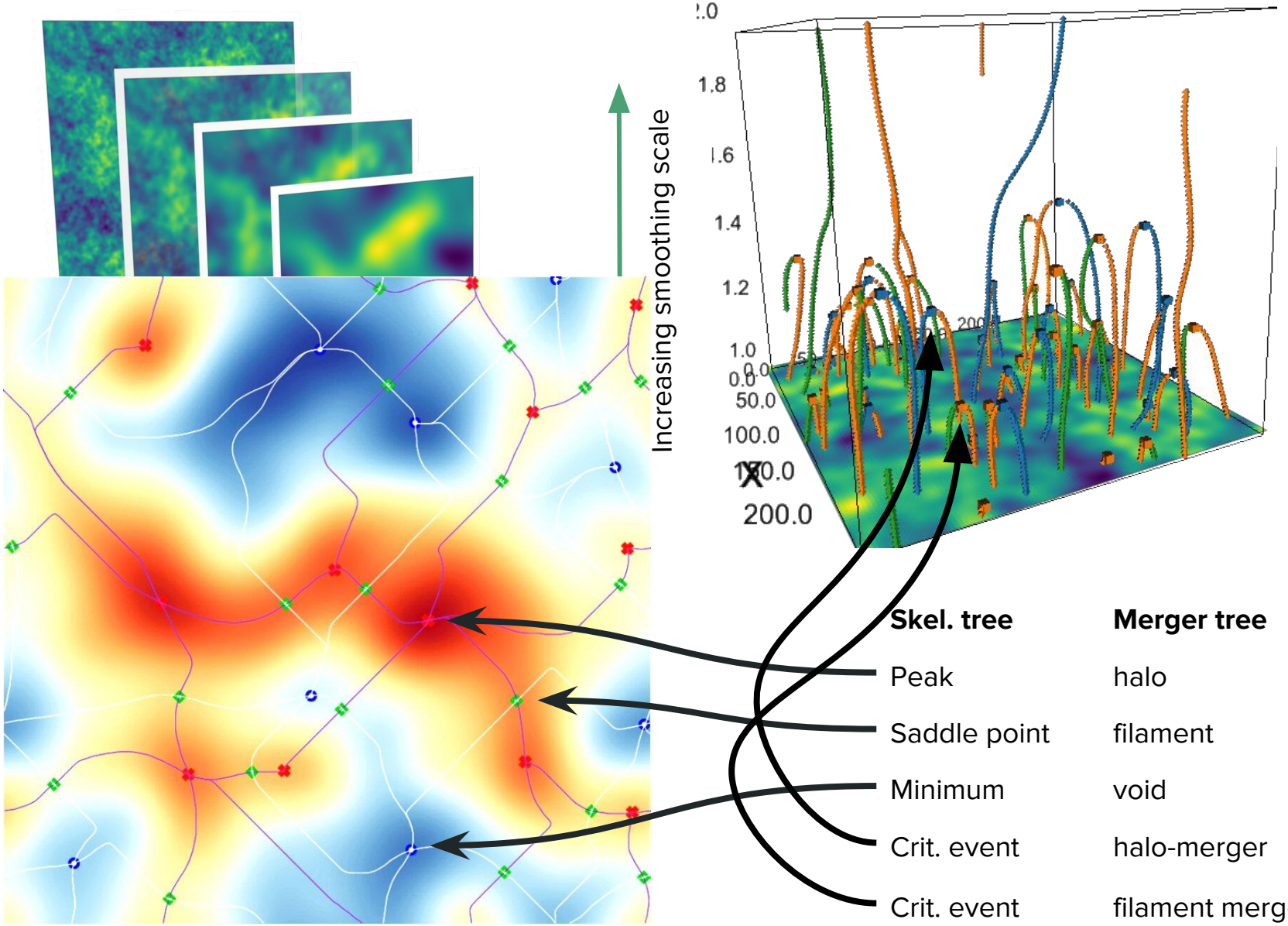
Building the skeleton tree







Building the skeleton tree



Why bother?

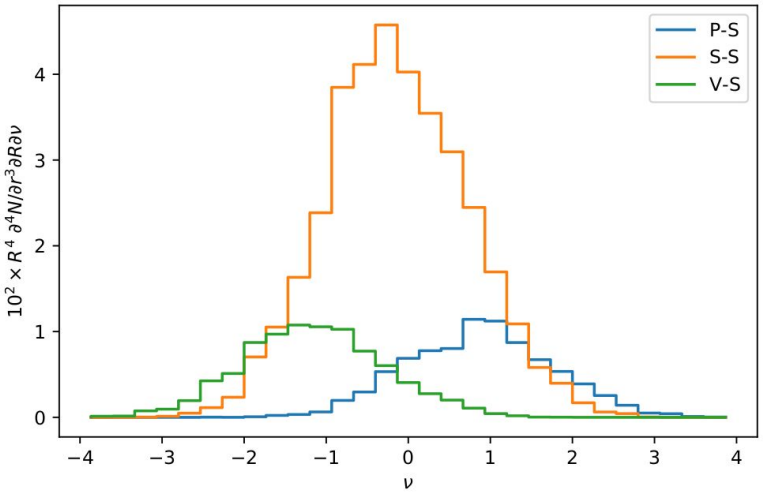
1. **cheap to generate** ➜ easy to get data
   - Generate ICs
   - Smooth at scale R
   - Find extrema
2. Statistics of the halo-mergers + filament-mergers ➜ **analytical**
   - How many filaments around halos?
   - Fraction of mass coming from filamentary accretion?

E.g.: number count per volume per smoothing scale is given by

$$\langle \delta_{\rm d}^{(3)}(x_i)\delta_{\rm d}(x_{33})\delta_{\rm d}(x-\nu)\times |x_{3ii}\,x_{333}|\times|x_{11}\,x_{22}-x_{12}^2|\rangle,$$

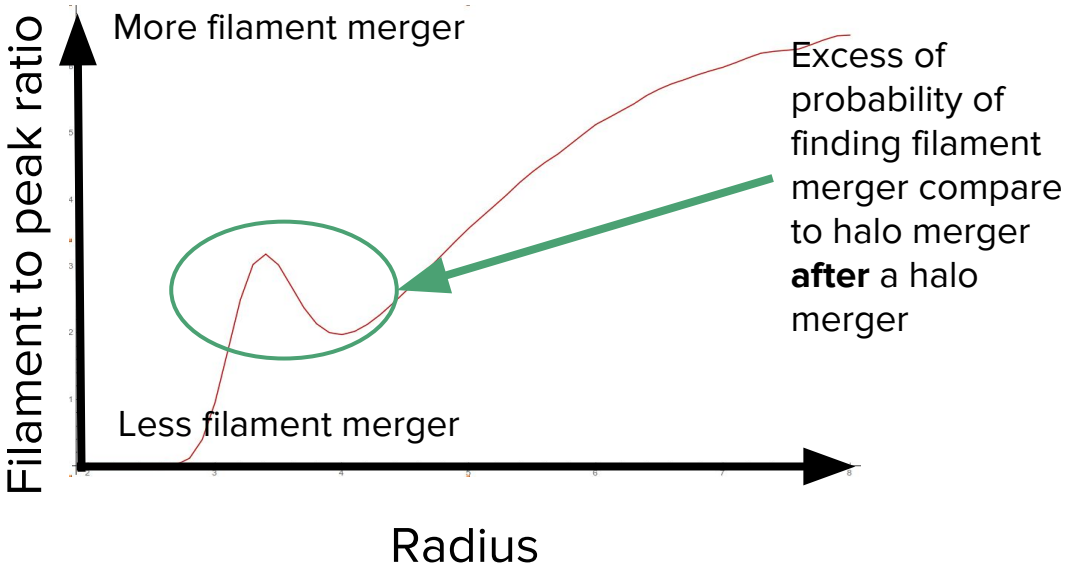
where

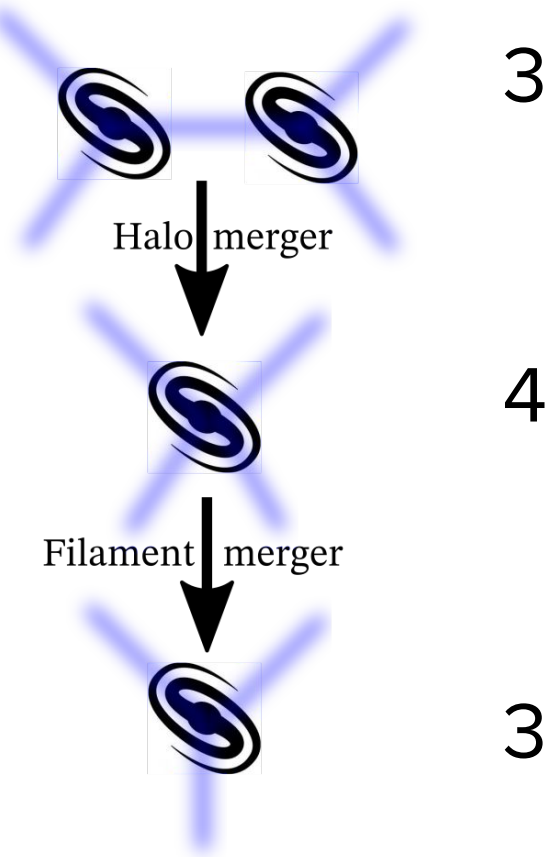
$$x_{i_1\ldots i_n}=\partial_{i_1}\ldots\partial_{i_n}x.$$



On the connectivity of halos

Compute frequency of filament merger compared to halo merger in the vicinity of a halo merger event $\xi_{\mathrm{hf}}(r)/\xi_{\mathrm{hh}}(r)$.



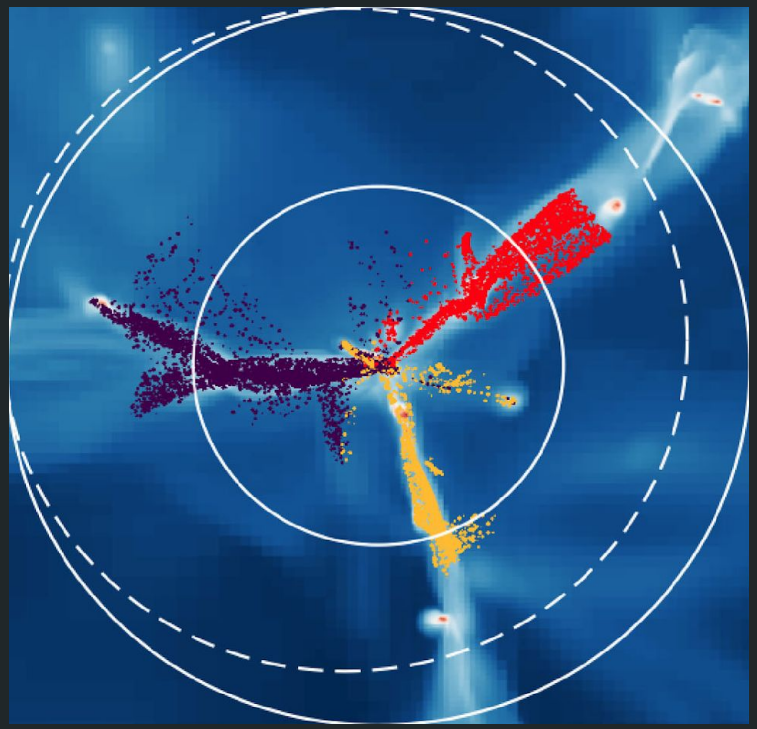


⇒ Excess probability of halo merger followed by filament merger

WIP

Linking LSS and galaxy formation

How is the information transported from the cosmic web to the small scale involved in galaxy formation?

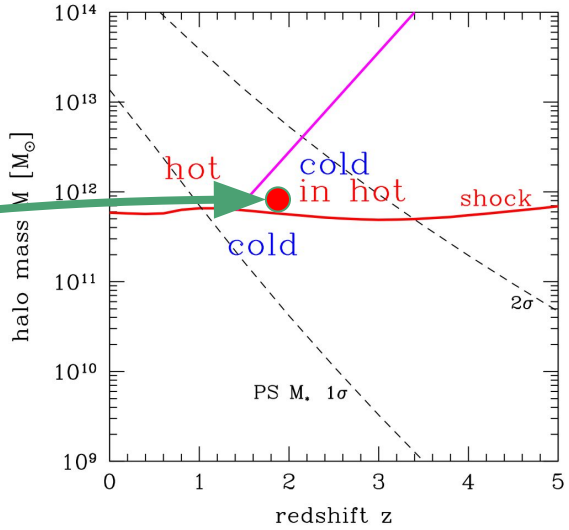


TIllson 2015

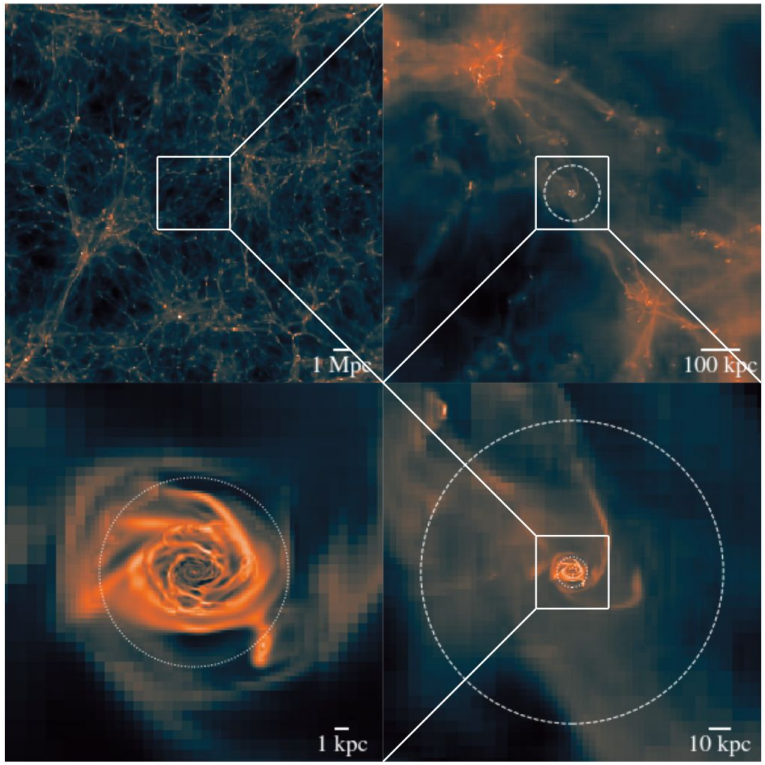
Filamentary accretion as bridge between large scales and galactic scales

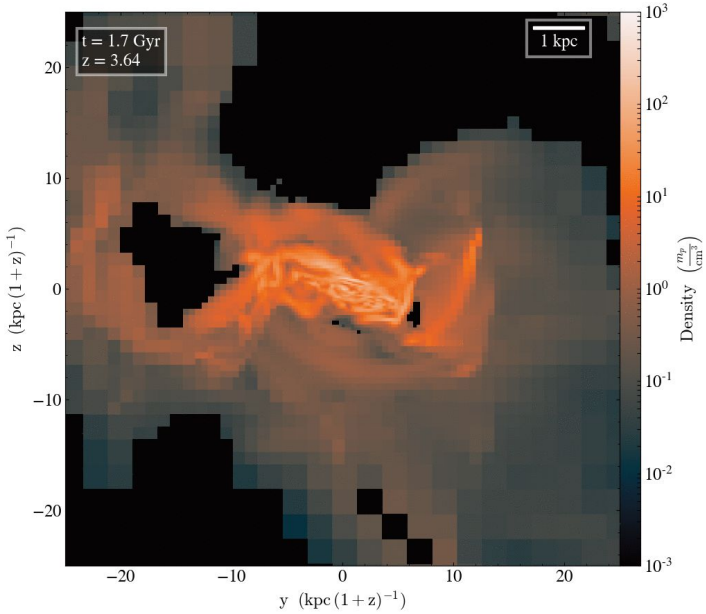
Numerical setup

- RAMSES, Δx = 30pc
- Turbulent star formation (Kimm+17, Trebitsch+17)
- $M=10^{12}M_{sun}$ at z=2
- 30,000,000 MC tracer particles (Cadiou+19)

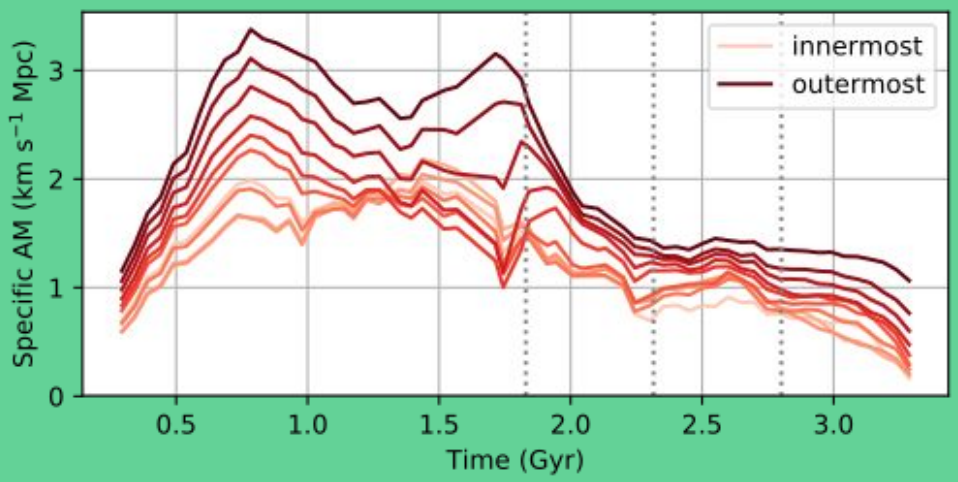


Dekel & Birnboim 06





Understand galaxy formation
⇒ understand transport of baryons



On the origin of torques

The evolution of the angular momentum of the gas follows (Danovich+15)

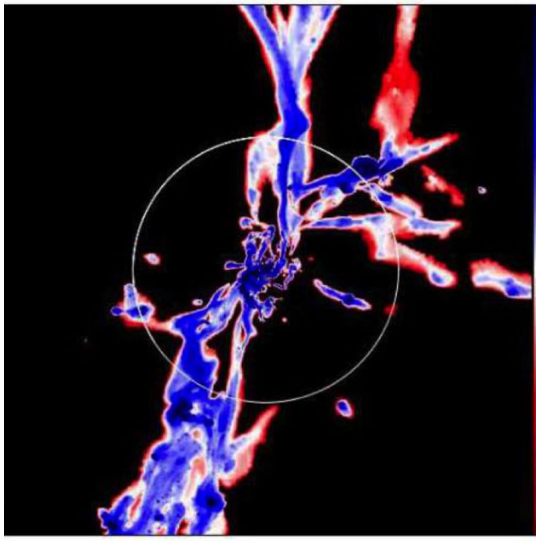
$$\vec{\tau} = \underbrace{-\rho\,\vec{r}\times\vec{\nabla}P}_{\text{Pressure torques}} \underbrace{-\vec{r}\times\vec{\nabla}\Phi}_{\text{Gravitational torques (gas, DM, stars)}} \underbrace{-\vec{l}\vec{\nabla}\cdot\vec{v}.}_{\text{Compression, shocks, . (conserves AM orientation !)}}$$

Lagrangian torque $\mathrm{d}\vec{l}/\mathrm{d}t$

Which one dominates? (red is pressure, blue is gravity)

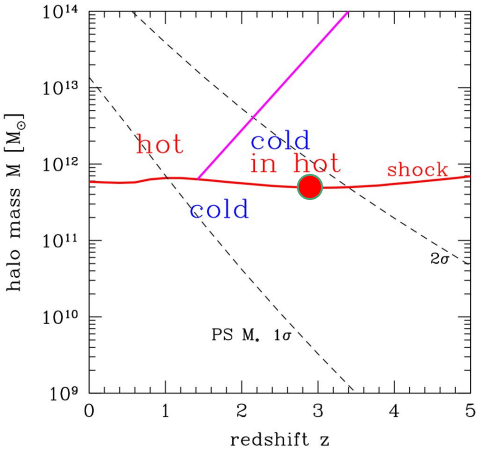
Prieto+2016: **Pressure** torques

or



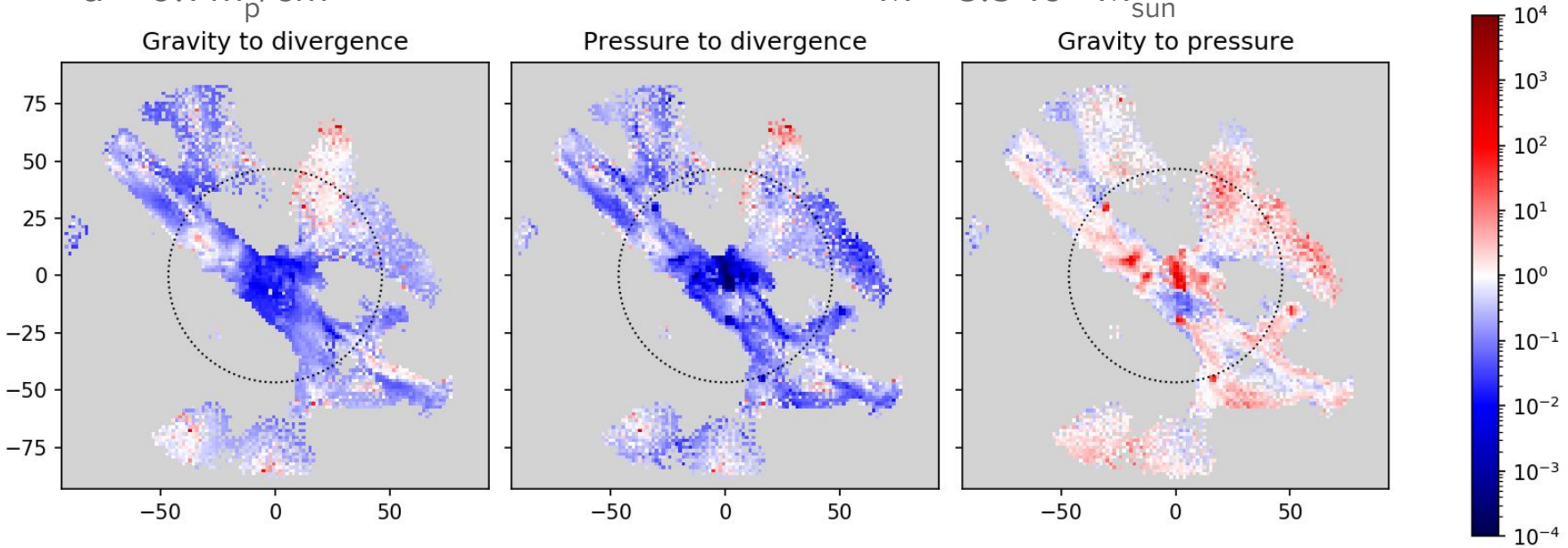
Danovich+2016: **Gravitational** torques

(Too?) early results



Ratio of torque <u>magnitude</u> (not taking into account orientation)

- $T < 10^5$ K
- $d < 0.1\ m_p/cm^3$
- $z = 2$
- $M = 3.3\ 10^{11}\ M_{sun}$

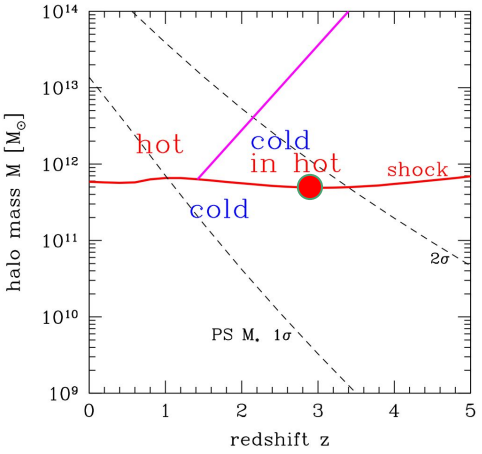


Gravity dominates outside inner halo

Pressure relevant in the center and outer region

Divergence term dominates everywhere?

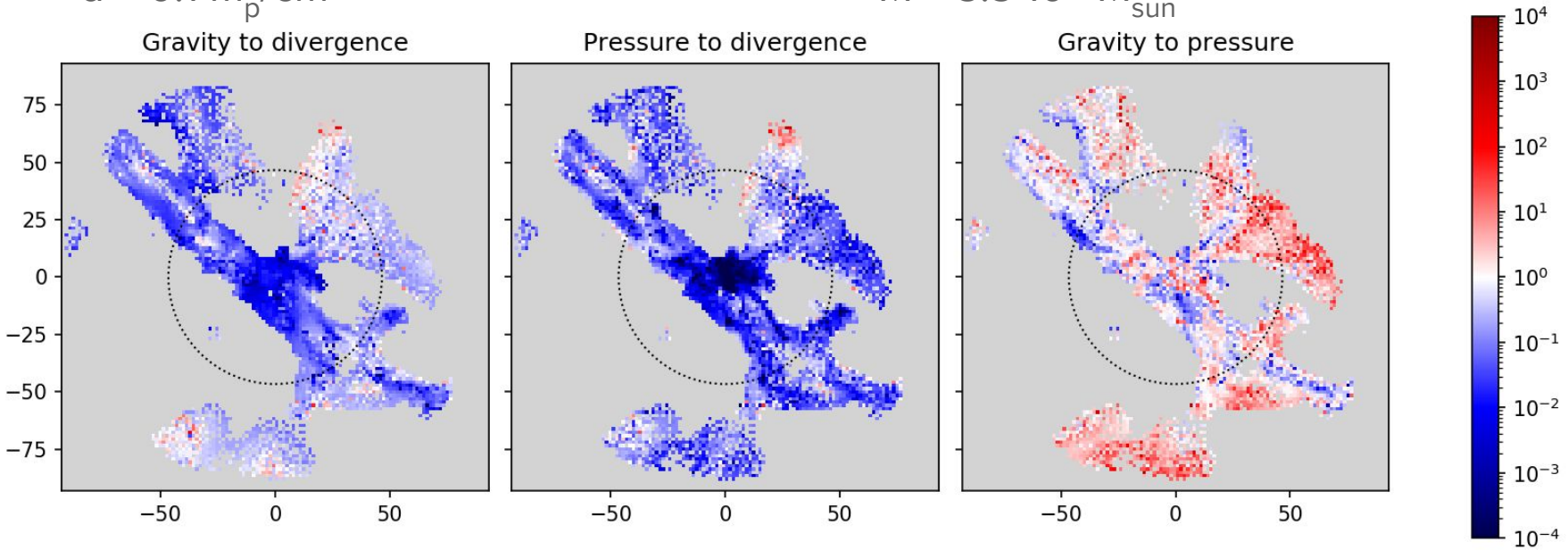
(Too?) early results



Ratio of torque orientation w.r.t. angular momentum

$$f_i \equiv \frac{\tau_i \cdot l}{l^2}$$

- $T < 10^5$ K
- $d < 0.1\ m_p/cm^3$
- $z = 2$
- $M = 3.3\ 10^{11}\ M_{sun}$



Gravity dominates outside Rvir

Mixed region within Rvir

Divergence term dominates everywhere?

Conclusion

Past, present and future

- Link between ICs and halo formation
  - [DONE] Effect of cosmic filaments on halo formation
  - [WIP] How many filaments around galaxy?
    - Effect of halo density?
    - Effect of neighboring large scale structure (halo, filament)? Bias-like effect
  - [FUTURE] Merger rate as a function of location in cosmic web
  - [FUTURE] Extend halo model with critical event space-time location

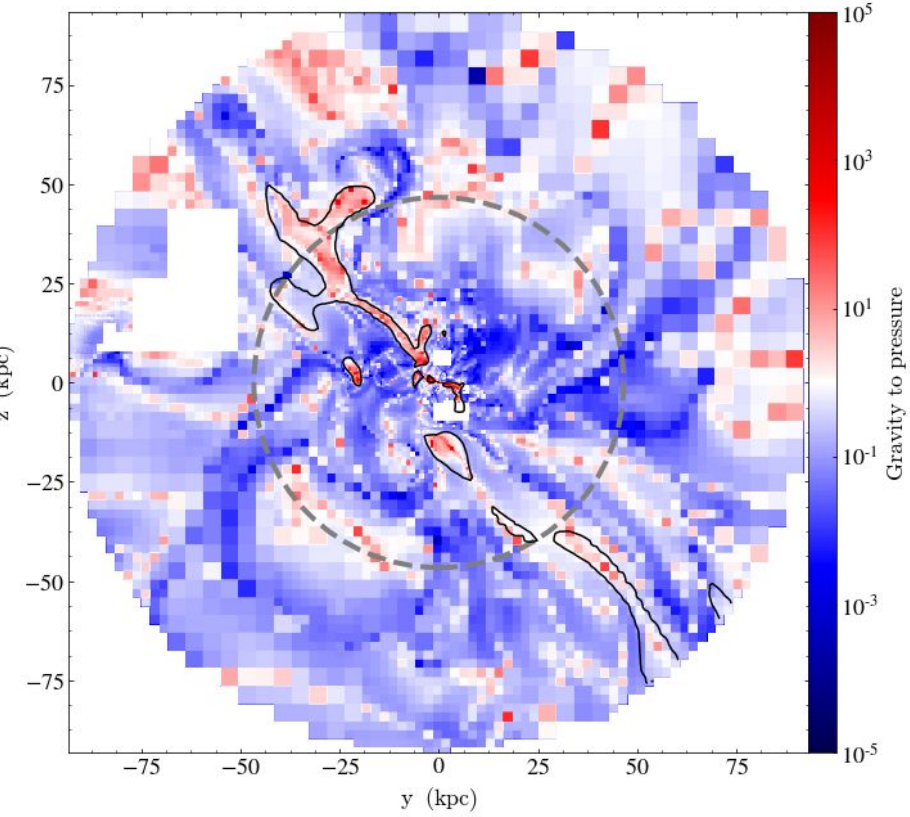
- Study of baryon transport in galaxies at z>2
  - [DONE] developed tracer particle scheme to track Lagrangian evolution
  - [DONE] new methods to extract torques due to different components
  - [WIP] study effect on galaxy assembly
    - [WIP] AM evolution dominated by divergence term? Then pressure?
    - Effect of cold accretion on disk buildup
    - Where does the AM goes?
  - [FUTURE] What about lower-mass galaxies?
  - [FUTURE] *Can we predict baryon spin?*

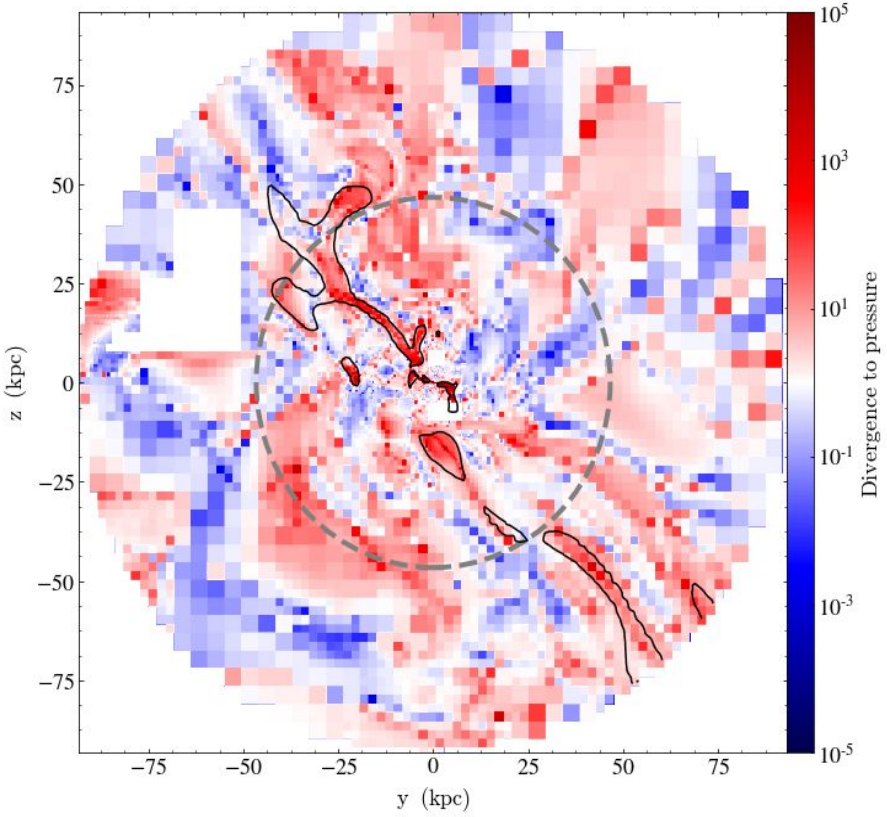
New-Horizon, Dubois in prep

Backup slides

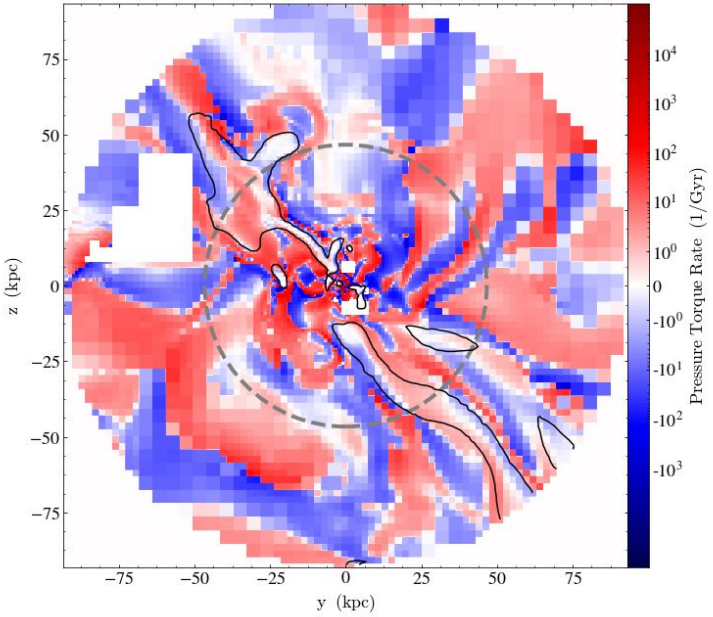
Or how to talk for way too long

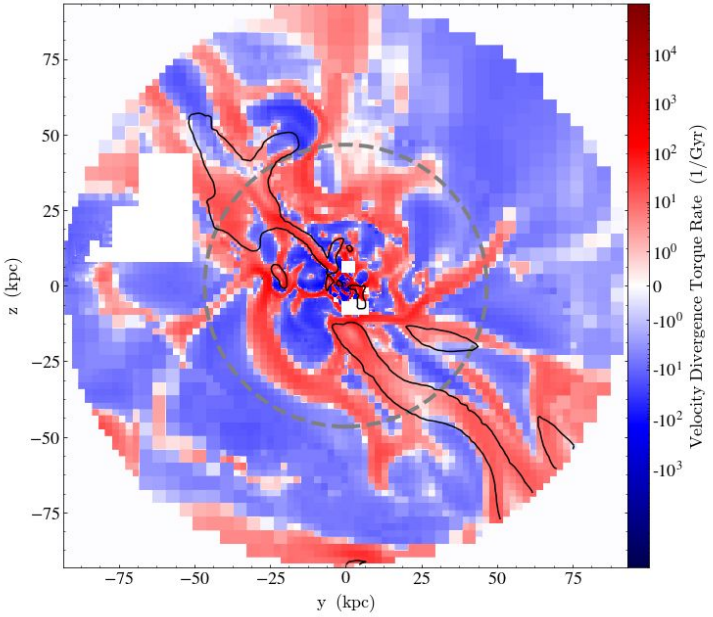
Slice of torque ratios





Slice of rates





$$f_i \equiv \frac{\tau_i \cdot l}{l^2}$$